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Effects of transglutaminase treatment on cooking quality, textural properties, and overall acceptability of high fibre pasta incorporated with pennywort residue

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Abstract

Pennywort juice is a herbal drink extracted from pennywort leaves and stems. Pennywort residue is a by-product of pennywort juice production. In the present work, this by-product was proved to be a good dietary fibre ingredient in the making of high fibre pasta. Nevertheless, the addition of 10% pennywort residue reduced cooking properties, textural profiles, and overall acceptability of the pasta samples. The effects of transglutaminase treatment of pasta dough on the product quality were then investigated. Increase in transglutaminase dosage from 0.00 to 0.75 U/g protein of the flour blend decreased the cooking loss of pasta by 19% while improving its tensile strength and elongation rate by 15 and 49%, respectively. Further increase in enzyme dosage from 0.75 to 1.00 U/g protein, on the other hand, decreased the tensile strength and elongation rate. When the enzyme treatment lasted for 30 min, the cooking loss was reduced by 10%, while the tensile strength and elongation rate of high fibre pasta were both enhanced by 10%. However, increase in treatment time from 30 to 40 min did not cause any significant differences in textural and cooking properties of the fibre-rich pasta. The appropriate transglutaminase dosage and biocatalytic time were 0.75 U/g protein and 30 min, respectively, under which the overall acceptability of the sample incorporated with 10% pennywort residue powder was similar to that of the semolina pasta.

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Introduction

Dietary fibre is highly important in the daily diet due to its benefits to human health, including improving the digestive system, reducing blood cholesterol, and preventing cardiovascular diseases (Fuller *et al*., 2016). Pasta is well known as a popular staple food with high starch content and reasonable price; however, it was reported to be poor in dietary fibre content with about 0.9 - 1.9 g/100 g product (Brennan, 2013). Recently, food industry by-products which contain high amount of fibre have been supplemented to pasta such as wheat bran (Nguyen *et al*., 2020), rice bran (Sethi *et al*., 2020), and oat bran (Espinosa-Solis *et al*., 2019). Other types of by-products, namely olive pomace (Simonato *et al*., 2019), orange pomace (Kaur *et al*., 2021), and apple pomace (Yadav and Gupta, 2015) were also added to fibre-rich pasta recipe. In addition, mango peel (Jalgaonkar *et al*., 2018) and grape peel (Iuga and Mironeasa, 2021) were proved to have potential in enriching the dietary fibre content of pasta. Many studies also reported the addition of tomato pomace (Padalino *et al*., 2017), carrot pomace (Gull *et al*., 2015), and broccoli by-product (Nogueira, 2022) to enhance dietary fibre content of the product.

Pennywort (*Centella asiatica* L.) is a herbaceous and potential medicinal plant in the Apiaceae family, which grows natively in tropical regions of Africa, Asia, Australia, and islands in the Western Pacific Ocean (Das, 2011). Pennywort leaves are reported to have different bioactive compounds including triterpenic acid, triterpenic saponin, and triterpene asiaticoside, which can stimulate the production of collagen in human body, and speed up wound healing process (Hashim *et al*.,

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2011). In addition, pennywort is also consumed as a vegetable (Das, 2011). In Southeast Asia, the leaves and stems of pennywort are used to produce pennywort juice. The production of pennywort juice generates pennywort residue, which contains non-extracted components such as dietary fibre. As such, pennywort residue can be a source of dietary fibre in the formulation of different food products.

The addition of external fibre sources to pasta recipe, on the other hand, may negatively affect the cooking quality, textural properties, and overall acceptability of pasta due to reduced gluten content (Gull *et al*., 2015; Padalino *et al*., 2017). There are several methods to overcome this situation (Ooms and Delcour, 2019), and transglutaminase (TG) treatment of pasta dough has attracted great attention since this method is simple and easy to be used in the industry (Ceresino *et al*., 2020). TG catalyses the reaction between ε-amino group of protein-bound lysine residues and β-carboxyamide group of protein-bound glutamine residues, thus leading to the formation of intra- and intermolecular covalent cross-links (Gharibzahedi *et al*., 2019). As a result, the use of this enzyme preparation improves the structural integrity of pasta products (Kumar *et al*., 2019).

In the present work, pennywort residue powder (PRP) was added to pasta formulation to make high fibre product. The objective was to investigate the effects of transglutaminase concentration and incubation time of the enzymatic treatment of pasta dough on the cooking quality, textural profile, and overall acceptability of high-fibre pasta.

Materials and methods

Materials

Pennywort residue was obtained from Kim Dung Pennywort Co. (Thu Duc, Ho Chi Minh City). Durum wheat semolina was purchased from Vietnam Wheat Milling Co., Ltd. (Ba Ria Vung Tau Province). Refined salt with added iodine was supplied by Southern Salt Group (Ho Chi Minh City). Transglutaminase (TG) preparation derived from *Streptomyces mobaraensis* (110 U/g) with the trade name Protiact TG-RA was purchased from Rama Production Co. (Sumutsakorn, Thailand). One unit (U) of TG activity was defined as the amount of enzyme that catalyses the formation of 1 μmol hydroxamate from N-carbobenzoxy-L-glutaminylglycine per minute under the assay conditions (Ando *et al*., 1989).

Analytical chemicals

Enzyme preparations namely glucoamylase Dextrozyme®GA, α-amylase Termamyl®SC, and protease Neutrase®2.5L used for dietary fibre determination were provided by Novozymes (Denmark). Chemicals with analytical grade were purchased from Sigma-Aldrich (USA) and Xilong Scientific Company (China).

Preparation of pennywort residue powder

The fresh pennywort residue (85 - 90% moisture content) was transported to the laboratory within 1 h after extraction, evenly spread on trays up to 1.5 cm of thickness, and dried at 55°C in a convectional dryer (Memmert Co., Germany). The residue was manually mixed every hour to efficiently evaporate off the moisture. The drying was carried out for 8 - 10 h until the final moisture content reached 10 - 13%. The dried product was then pulverised using a HR2056 blender (Philips Co., The Netherlands), and sieved through a 70-mesh (0.210 mm) screen. The product powder was transferred into polyethylene bags, which were then placed into Styrofoam boxes, and stored at 4°C until subsequent analyses.

Preparation of pasta

In this recipe, durum wheat semolina and PRP with a total weight of 150 g, and 0.75 g of salt were mixed. The ratios of pennywort powder were 0% (C; control) and 10% of the flour blend weight (P; PRP-incorporated pasta). Then, 80 mL of distilled water at 42°C was added, since temperatures between 40 - 50°C are considered appropriate for pasta-making, as they are not associated with significant denaturation of proteins and starch gelatinisation, but facilitate the extrusion of the dough by decreasing its viscosity (Bresciani *et al*., 2022). The mixture was mixed at 120 rpm for 2 min, and kneaded at 120 rpm for 20 min using the same stand mixer (Ichiban Ltd., Japan) to produce a uniform dough. After that, the dough was fed to a HR2365/05 extruder (Philips Co., China) with the extrusion pressure of 720 kgf/cm^2 and die diameter of 1.6 mm to produce pasta strands. The product was dried with hot air at 50°C using a convectional dryer (Memmert Co., Germany) until it reached 9 - 11% moisture content. Dried pasta was packed in metallised polyester bag, and stored at ambient temperature for 1 w until further analyses.

In the preparation of TG-treated pasta, TG was dissolved in distilled water at 42°C. In the first

experiment, different ratios of the enzyme preparation were added to the blend which contained 90% semolina and 10% PRP before kneading. The enzyme dosages were 0.25, 0.50, 0.75, and 1.00 U/g protein of the flour blend for the sample codes P25E, P50E, P75E, and P100E, respectively. These non-incubated pasta samples preparation was performed under the same conditions as previously described. In the second experiment, TG dosage of 0.75 U/g protein was selected. After kneading, the treated doughs were put on trays, covered with plastic wrap, and incubated at 40°C. The incubation times were 10, 20, 30, and 40 min for the sample codes P75E10T, P75E20T, P75E30T, and P75E40T, respectively. After incubation, the remaining steps were done following the recipe mentioned earlier.

Analytical methods

The total protein and starch contents were measured using AOAC 984.13 and 996.11 methods, respectively. The lipid content was quantified by Soxhlet method following AOAC 960.39 method. The total, insoluble, and soluble dietary fibre (TDF, IDF, and SDF) contents were evaluated using AOAC 985.29, 991.42, and 991.43 methods, respectively. The ash content was determined following AOAC 9930.30 method. The optimal cooking time, cooking loss, swelling, and water absorption index of pasta samples were determined according to Nguyen *et al*. (2020). For cooking quality, 10 g of each pasta sample was broken into 5 cm lengths, and cooked in 100 mL of boiling distilled water. The optimal cooking time was the time when the white inner core of the pasta disappeared. At the end of cooking, the pasta strands were removed, drained for 2 min, and weighed. The cooked and drained pasta strands were dried to constant weight at 105°C. To determine the total dry matter, the cooking water was evaporated to dryness at 105°C. Cooking loss was calculated by dividing the total dry matter of cooking water by the dry weight of raw pasta. The swelling index (SI) and the water absorption index (WAI) were calculated using the formula described by Foschia *et al*. (2015). Instrumental colours including L*, a*, and b* indexes were analysed using a CM-3700A colorimeter (Konica Minolta, Japan); the colour differences between pasta samples were calculated according to Nguyen *et al*., 2020. Textural parameters including hardness, cohesiveness, gumminess, tensile strength, and elongation rate of pasta samples were measured using a P35 probe, TA-TX structural analyser (Stable Micro Systems Co., UK) coupled with the Exponent Connect Lite 7.0 software. Hardness was the peak force during the first compression cycle. Cohesiveness was the ratio of energies expanded in the first and second cycles. Gumminess was calculated by multiplying the hardness and the positive area ratio between the second and first compression cycles. Chewiness was the product of the gumminess and the compression distance ratio between the second and first compression cycles (Mochizuki, 2001). In addition, the formulas for determining tensile strength and elongation rate of pasta samples were described by Nguyen *et al*. (2020). Sensory evaluation of pasta samples was performed using a nine-point hedonic scale, ranging from 1 (extremely dislike) to 9 (extremely like) (Nguyen *et al*., 2020). Sixty untrained panellists were chosen at random from Ho Chi Minh City University of Technology students, without gender consideration. The panellists were asked to eat the cooked pasta samples, and rate their overall acceptability based on colour, texture, taste, and flavour.

Statistical analysis

All the experiments were run in triplicate to calculate the mean value. The results were presented as mean ± standard deviation. One-way analysis of variance (ANOVA) was done using the Statgraphics Centurion XVI software (USA). The multiple range test ($p < 0.05$) was used to determine significant differences.

Results and discussion

Proximate composition of pasta samples

The proximate compositions of semolina pasta (sample C) and 90% semolina and 10% pennywort residue pasta (sample P) are shown in Figure 1. The protein, lipid, and ash contents of pasta samples incorporated with PRP was 1.1, 1.3, and 1.7 times, respectively, higher than those of the conventional pasta sample. On the contrary, the pennywort-incorporated pasta sample had starch content of 70.2 ± 1.3 (% dw), which was 6% lower than that of the control sample. The dietary fibre content is an important indicator to evaluate the potential use of PRP as a source of dietary fibre in the formulation of food products. In the present work, the soluble, insoluble, and total dietary fibre contents of pasta incorporated with 10% PRP were approximately 1.5,

2.6, and 2.4 times, respectively, higher than those of the control pasta. Similar change in proximate composition was previously recorded in the study of Nongrum *et al*. (2020) when pennywort powder was added to noodle formulations. It should also be noted that at 10% PRP ratio, the total dietary fibre content of the incorporated pasta was 8.3 ± 0.3 (%, dw), which was much higher than 6 (%, dw) - the minimum fibre content for a food product to be called "*High Fibre Product*" (Bröring and Khedkar, 2018). The aforementioned results proved that PRP could be a good dietary fibre source for pasta supplementation. However, rich-fibre pasta was reported to have decreased cooking, textural, and sensorial properties (Gull *et al*., 2015; Padalino *et al*., 2017; Le *et al*., 2023). In order to enhance the quality of pasta incorporated with 10% PRP, the treatment of pasta dough with TG preparation was therefore essential.

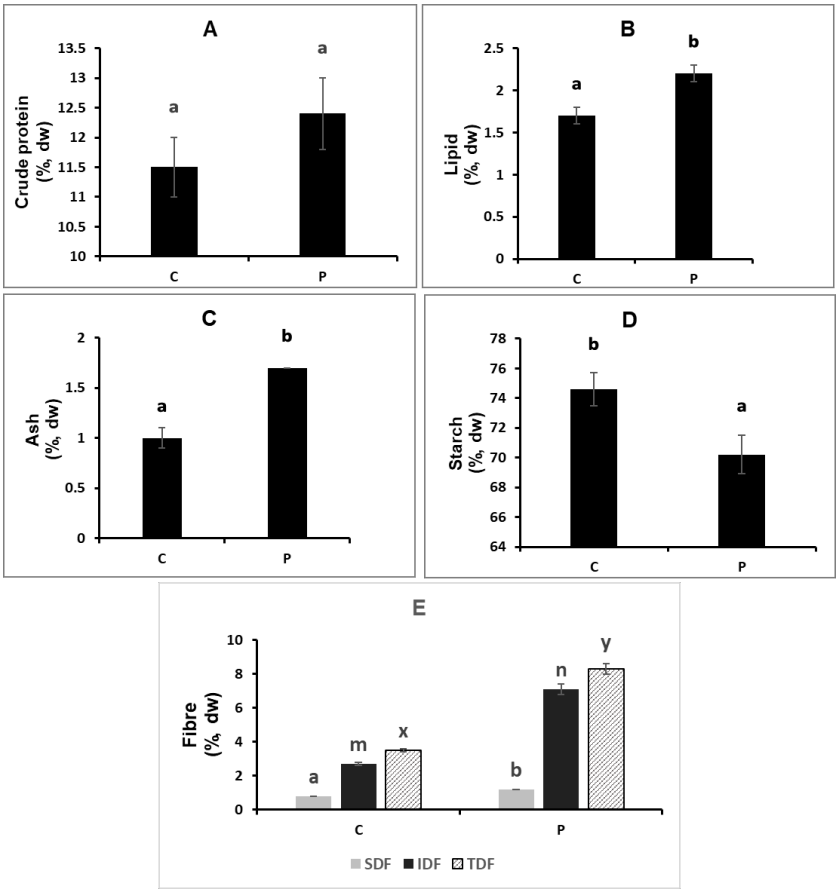

Figure 1. Crude protein **(A)**, lipid **(B)**, ash **(C)**, starch **(D)**, and fibre **(E)** contents of pasta from 100% semolina (C) and pasta from 90% semolina and 10% pennywort residue powder (P). dw: dry weight; SDF: soluble dietary fibre; IDF: insoluble dietary fibre, and TDF: total dietary fibre. Values that do not share similar lowercase letter ($^{a\text{-}b}$), ($^{m\text{-}n}$), and ($^{x\text{-}y}$) within each sub-figure are significantly different ($p < 0.05$).

Effects of transglutaminase concentration on quality of pasta with 10% pennywort residue powder

Table 1 presents the effects of transglutaminase (TG) concentration on the cooking quality, texture profile, and colour values of pasta incorporated with 10% PRP. When TG concentration was increased from 0.00 to 0.75 U/g of protein of the flour blend, the optimal cooking time was increased by 13% while the cooking loss was decreased by 19%. The cross-links formed between protein molecules during the enzymatic treatment might help strengthen the protein network which acted as a barrier to prevent water penetration inside the core of the products (Kim *et al*., 2014). However, when TG concentration was increased from 0.75 to 1.00 U/g protein, the optimal cooking time decreased while the cooking loss significantly increased. It can be explained that the intensified cross-linking at high TG concentration might have weakened the protein-starch interactions in the pasta dough, thus promoting the leakage of starch granules, soluble dietary fibre, and other water-soluble molecules to the external environment and the diffusion of cooking water to the core of spaghetti samples (Aalami and Leelavathi, 2008; Aravind *et*

Table 1. Effects of transglutaminase concentration on cooking quality, textural profile, and colour values of pasta with 10% pennywort residue powder.

Parameter	Sample					
	C	**P**	**P25E**	**P50E**	**P75E**	**P100E**
Optimal cooking time (min)	14.7 ± 0.3^{e}	12.6 ± 0.5^{b}	12.8 ± 0.7^{bc}	13.3 ± 0.5^{c}	14.2 ± 0.4^{d}	11.8 ± 0.3^{a}
Cooking loss (%)	3.3 ± 0.3^{a}	4.8 ± 0.1^{d}	4.5 ± 0.2^{cd}	4.4 ± 0.2^{c}	3.9 ± 0.1^{b}	4.8 ± 0.3^{cd}
Swelling index	2.4 ± 0.1^{b}	1.9 ± 0.0^{a}	1.8 ± 0.1^{a}	1.8 ± 0.0^{a}	1.8 ± 0.1^{a}	1.8 ± 0.0^{a}
Water absorption index	1.8 ± 0.1^{c}	1.5 ± 0.0^{ab}	1.5 ± 0.1^{b}	1.5 ± 0.0^{b}	1.5 ± 0.1^{b}	1.3 ± 0.0^{ab}
Hardness (g)	2020 ± 38^{a}	2701 ± 37^{b}	2777 ± 72^{b}	2783 ± 39^{b}	2951 ± 56^{c}	2694 ± 39^{b}
Cohesiveness	0.54 ± 0.03^{c}	0.46 ± 0.02^{a}	0.46 ± 0.03^{a}	0.48 ± 0.02^{ab}	0.51 ± 0.03^{bc}	0.47 ± 0.02^{ab}
Gumminess (g)	1084 ± 53^{a}	1243 ± 41^{b}	1279 ± 41^{bc}	1337 ± 48^{c}	1505 ± 39^{d}	1266 ± 51^{bc}
Chewiness (g)	1044 ± 92^{a}	1227 ± 43^{b}	1263 ± 40^{bc}	1320 ± 49^{c}	1486 ± 47^{d}	1250 ± 43^{bc}
Elongation rate (%)	56.1 ± 2.1^{d}	34.0 ± 1.3^{a}	36.0 ± 1.6^{a}	40.4 ± 1.3^{b}	50.8 ± 1.1^{c}	34.8 ± 1.2^{a}
Tensile strength (KPa)	31.5 ± 1.4^{d}	26.0 ± 1.1^{a}	27.2 ± 1.4^{ab}	28.3 ± 1.1^{bc}	30.0 ± 1.1^{cd}	28.4 ± 1.1^{bc}
L*	-	70.57 ± 0.31^{a}	72.48 ± 0.44^{b}	74.61 ± 0.27^{c}	75.28 ± 0.16^{d}	75.55 ± 0.44^{d}
a*	-	0.08 ± 0.01^{a}	0.23 ± 0.01^{b}	0.34 ± 0.02^{c}	0.56 ± 0.03^{d}	0.53 ± 0.04^{d}
b*	-	13.17 ± 0.23^{a}	13.28 ± 0.18^{a}	13.68 ± 0.34^{b}	14.68 ± 0.04^{c}	14.63 ± 0.17^{c}
ΔE	-	0.00 ± 0.00^{a}	1.92 ± 0.45^{b}	4.09 ± 0.31^{c}	4.97 ± 0.14^{d}	5.22 ± 0.40^{e}

Values are mean ± standard deviation. Means that do not share similar lowercase superscripts within a row are significantly different ($p < 0.05$). C: pasta from 100% semolina; P, P25E, P50E, P75E, and P100E: pasta from 90% semolina, 10% pennywort residue powder, and treated with TG at 0.00, 0.25, 0.50, 0.75, and 1.00 U/g protein of the flour blend, respectively.

al., 2012). The swelling and water absorption index of pasta incorporated with 10% PRP remained nearly unchanged when the TG dosages were ranged from 0.00 to 1.00 U/g protein. The TG treatment did not affect the starch content of pasta samples. Therefore, the differences in water absorption and swelling index could only have been attributed to the different distribution of starch granules in the gluten network of TG-treated pasta (Aalami and Leelavathi, 2008).

Increase in TG concentration from 0.00 to 0.75 U/g protein increased the hardness of high-fibre pasta due to the strengthened gluten network as discussed earlier. Cohesiveness represents the ability of a material to stick to itself (Bustos *et al*., 2015). In the present work, the reinforced gluten matrix significantly decreased the cooking loss of treated pasta while improving its cohesiveness by 11% when the TG dosage was increased from 0 to 0.75 U/g protein of the flour blend. A result reported by Lu *et al*. (2009) also demonstrated a negative correlation between cohesiveness and cooking loss when they investigated the effects of flour free lipids on the textural and cooking properties of Chinese noodles. Similarly, the gumminess and chewiness of high fibre pasta sample treated with 0.75 U/g protein TG were 21 and 21%, respectively, higher than those of the untreated pasta (P sample). When the TG dosage was increased from 0.00 to 0.75 U/g protein, the tensile strength and elongation rate of the product were also increased by 15 and 49%, respectively. Nevertheless, further increase in enzyme concentration from 0.75 to 1.00 U/g of protein decreased many textural properties of pasta since the excessive crosslinks of protein molecules might disturb the balance of protein-starch interactions, thus weakening the structural network of pasta (Wu and Corke, 2005). Similar change in textural profiles was also observed in the study of Wu and Corke (2005) when TG was used in the treatment of noodles made from two different commercial brands of wheat flour, which were Red Bicycle (US) and Sandow (Hong Kong).

The increased level of TG from 0.00 to 0.75 U/g protein in the treatment also increased the L* values of pasta fortified with 10% of PRP by 7%. Similar results were reported in the study of Yalcin and Basman (2008) who suggested that the free amino radicals (-NH_2) of dough protein might participate in the acyl transfer reaction during the TG treatment instead of taking part in Maillard reaction during the pasta drying and storing processes, thereby reducing browning and increasing the brightness of pasta (Yalcin and Basman, 2008). Nevertheless, the colour difference between all high-fibre pasta samples fortified with 10% PRP was not high enough for visual observation since the ΔE value varied from 0.00 to 5.22.

Figure 2 shows that all pasta samples incorporated with 10% PRP and treated with TG had lower overall acceptability than the semolina pasta (sample C). When the TG concentration was increased from 0.00 to 0.75 U/g protein, the overall acceptability of pasta increased by approximately 20%. This might be due to the improvement in texture properties of the product. The increased overall acceptability of olive powder-incorporated pasta was also reported at an increased TG dosage during the enzymatic treatment of pasta dough (Simonato *et al*., 2019). In contrast, further increase in TG concentration from 0.75 to 1.00 U/g protein slightly decreased the overall acceptability probably due to the reduction in elongation rate and tensile strength of the cooked pasta since these textural properties are highly important for consumers (Niu *et al*., 2017).

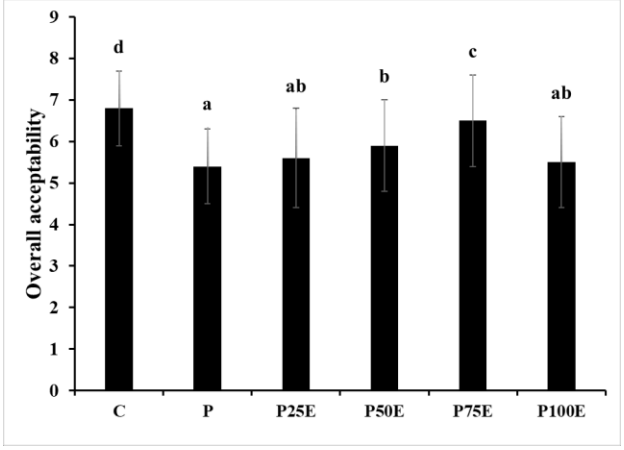

Figure 2. Effects of transglutaminase concentration on overall acceptability of pasta with 10% pennywort residue powder. Values that do not share similar lowercase letter ($^{a\text{-}e}$) within a row are significantly different ($p < 0.05$). C: pasta from 100% semolina; P, P25E, P50E, P75E, and P100E: pasta from 90% semolina, 10% pennywort residue powder, and treated with TG at 0.00, 0.25, 0.50, 0.75, and 1.00 U/g protein of the flour blend, respectively.

Effects of transglutaminase treatment time on quality of pasta with 10% pennywort residue powder

The effects of incubation time of the TG treatment on cooking quality, texture profile, and colour values of 10% PRP-incorporated pasta are illustrated in Table 2. The increased biocatalytic time

Table 2. Effects of transglutaminase treatment time on cooking quality, textural profile, and colour values of pasta with 10% pennywort residue powder.

Parameter	Sample						
	C	**P**	**P75E**	**P75E10T**	**P75E20T**	**P75E30T**	**P75E40T**
Optimal cooking time (min)	14.9 ± 0.1^{d}	12.7 ± 0.3^{a}	14.1 ± 0.4^{b}	14.2 ± 0.3^{b}	14.3 ± 0.4^{bc}	14.7 ± 0.1^{cd}	14.5 ± 0.3^{bcd}
Cooking loss (%)	3.1 ± 0.2^{a}	4.7 ± 0.1^{c}	3.9 ± 0.1^{b}	3.9 ± 0.1^{b}	3.8 ± 0.2^{b}	3.5 ± 0.1^{a}	3.4 ± 0.2^{a}
Swelling index	2.4 ± 0.2^{b}	1.8 ± 0.0^{a}	1.8 ± 0.1^{a}	1.8 ± 0.1^{a}	1.9 ± 0.1^{a}	1.9 ± 0.1^{a}	1.9 ± 0.1^{a}
Water absorption index	1.9 ± 0.0^{d}	1.4 ± 0.0^{a}	1.5 ± 0.1^{ab}	1.5 ± 0.1^{abc}	1.6 ± 0.1^{bcd}	1.6 ± 0.0^{d}	1.6 ± 0.0^{cd}
Hardness (g)	2025 ± 58^{a}	2726 ± 79^{b}	2946 ± 45^{c}	2983 ± 42^{cd}	2966 ± 49^{c}	3070 ± 75^{d}	3064 ± 60^{d}
Cohesiveness	0.55 ± 0.03^{d}	0.47 ± 0.01^{a}	0.50 ± 0.02^{ab}	0.51 ± 0.02^{bc}	0.51 ± 0.01^{bc}	0.53 ± 0.01^{cd}	0.53 ± 0.03^{cd}
Gumminess (g)	1103 ± 39^{a}	1261 ± 70^{b}	1503 ± 41^{c}	1552 ± 50^{cd}	1573 ± 47^{cde}	1628 ± 50^{e}	1623 ± 45^{de}
Chewiness (g)	1059 ± 44^{a}	1312 ± 5^{b}	1423 ± 48^{c}	1486 ± 41^{cd}	1520 ± 36^{d}	1754 ± 45^{e}	1748 ± 38^{e}
Elongation rate (%)	57.3 ± 1.2^{d}	33.9 ± 1.6^{a}	49.8 ± 1.5^{b}	50.5 ± 1.7^{b}	50.3 ± 1.4^{b}	54.8 ± 1.0^{c}	54.5 ± 1.6^{c}
Tensile strength (KPa)	32.1 ± 0.8^{cd}	26.1 ± 1.1^{a}	30.0 ± 1.0^{b}	30.2 ± 1.0^{bc}	31.6 ± 1.5^{bcd}	33.1 ± 0.9^{d}	33.2 ± 1.3^{d}
L*	-	70.93 ± 0.13^{a}	75.55 ± 0.30^{b}	75.56 ± 0.29^{b}	75.34 ± 0.32^{b}	75.61 ± 0.34^{b}	75.48 ± 0.42^{b}
a*	-	0.07 ± 0.01^{a}	0.58 ± 0.01^{b}	0.57 ± 0.01^{b}	0.58 ± 0.03^{b}	0.57 ± 0.02^{b}	0.60 ± 0.04^{b}
b*	-	13.28 ± 0.05^{a}	14.3 ± 0.27^{b}	14.39 ± 0.51^{b}	14.59 ± 0.34^{b}	14.68 ± 0.8^{b}	14.65 ± 0.10^{b}
ΔE	-	0.00 ± 0.00^{a}	4.77 ± 0.27^{bc}	4.80 ± 0.36^{bc}	4.64 ± 0.33^{b}	4.94 ± 0.49^{c}	4.79 ± 0.37^{bc}

Values are mean ± standard deviation. Means that do not share similar lowercase superscripts within a row are significantly different ($p < 0.05$). C: pasta from 100% semolina; P: pasta from 90% semolina and 10% pennywort residue powder without transglutaminase treatment; P75E, P75E10T, P75E20T, P75E30T, and P75E40T: pasta from 90% semolina, 10% pennywort residue powder, and treated with TG at 0.75 U/g protein of the flour blend, and incubated for 0, 10, 20, 30, and 40 min, respectively.

increased the optimal cooking time of pasta, but decreased its cooking loss by 10%. There were no significant differences in optimal cooking time and cooking loss between the three samples: C, P75E30T, and P75E40T. Therefore, 30 min seemed to be an adequate time of TG treatment to firmly strengthen protein network of the high-fibre pasta. The change in TG treatment time did not alter much the swelling and water absorption index of the pasta samples. Similar results were previously reported when the impacts of TG incubation time on the quality of spaghetti incorporated with durum pollard and guar gum were investigated (Sissons *et al*., 2010).

Besides, the hardness, cohesiveness, gumminess, and chewiness of pasta were enhanced when the incubation time lasted from 0 to 30 min due to the increased number of crosslinks within the protein network of pasta (Kim *et al*., 2014). Then, these textural properties remained statistically similar with further increase in enzyme treatment duration. Table 2 also reveals that the elongation rate and tensile strength of P75E30T sample were significantly greater than those of P75E sample. However, when the incubation time was increased from 30 to 40 min, the TG treatment had no further effect on textural properties of the high-fibre pasta. Takács *et al*. (2008) demonstrated that the incubation intervals ranging between 30 to 180 min did not appreciably affect the water uptake and cooking loss of pasta made from *T. aestivum* and *T. durum* flour, which were directly related to the textural quality of treated samples.

The ΔE value of the TG treated samples were not significantly different when the incubation time was changed from 0 to 40 min. Obviously, it was hard to distinguish the difference in colour of the TG treated samples since their L*, a*, and b* values were also not statistically different.

Figure 3 shows that at the TG concentration of 0.75 U/g protein, the overall acceptability of pasta incorporated with 10% PRP tended to increase slightly when the incubation time was increased from 0 to 40 min due to the enhancement of textural properties of the product. With the incubation duration of 30 or 40 min, the high-fibre pasta samples had similar overall acceptability to the control (sample C). The appropriate TG treatment time for pasta incorporated with PRP, as a result, was 30 min.

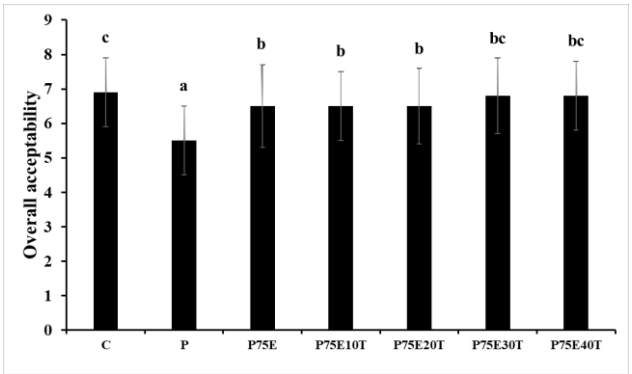

Figure 3. Effects of transglutaminase treatment time on overall acceptability of pasta with 10% pennywort residue powder. Values that do not share similar lowercase letter ($^{a-e}$) within a row are significantly different ($p < 0.05$). C: pasta from 100% semolina; P: pasta from 90% semolina, 10% pennywort residue powder without transglutaminase treatment; P75E, P75E10T, P75E20T, P75E30T, and P75E40T: pasta from 90% semolina, 10% pennywort residue powder, and treated with transglutaminase at 0.75 U/g protein of the flour blend, and incubated for 0, 10, 20, 30, and 40 min, respectively.

Conclusion

The present work proved that pasta fortified with 10% PRP could be a high-fibre food product. When the TG dosage was increased from 0.00 to 0.75 U/g protein of the flour blend, the cooking loss was significantly decreased while the textural properties such as gumminess, chewiness, tensile strength, and elongation rate of pasta were increased. Further increase in TG level from 0.75 to 1.00 U/g protein of the flour blend, in contrast, enhanced the cooking loss while reduced the textural properties of the high-fibre pasta. In addition, the increase in TG treatment time from 0 to 30 min slightly decreased the cooking loss, whereas gradually enhanced the optimal cooking time and textural properties of pasta. Nevertheless, when the incubation time was prolonged from 30 to 40 min, the textural profile of pasta remained unchanged. At TG concentration of 0.75 U/g protein of flour blend and an incubation duration of 30 min, the overall acceptability of the PRP incorporated pasta and 100% semolina pasta was statistically similar. In the future, glycaemic index and antioxidant bioaccessibility of the fibre-rich pasta should be investigated to clarify its health benefits for human nutrition.

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